



Original Research Paper

Geospatial Suitability Mapping of Climate-based Disease Transmission using Fuzzy Logic for Central India

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Abstract

Geographic Information System (GIS) today supports health and disease mapping in diverse ways. Present study divulges geographic dimensions of malaria disease in Madhya Pradesh and Chhattisgarh states located in Central India. Chhattisgarh is second and Madhya Pradesh is the third most malarious states after Odisha in India. In the present study, an attempt is made to map climate-based malaria transmission suitability using fuzzy logic for Central India. Temperature and relative humidity were selected as the two indicators for malaria transmission suitability analysis. District wise meteorological data for 2008 was used for the present study. Monthly temperature and relative humidity interpolation maps were generated using 'Natural Neighbor' interpolation algorithm. For both the indicators trapezoidal membership function was selected. Arc GIS software and its FUZZY tool were used to generate 'climate suitability map' for malaria transmission depicting the spatial distribution of Transmission Window length (in months) across the region. The findings illustrate that most districts of Chhattisgarh and very few districts of Madhya Pradesh have transmission window open for more than 10 months and are identified as 'High Endemic Regions'. Compared to Chhattisgarh, Madhya Pradesh experiences more numbers of least suitable months i.e. February, March, April and May. The study aims to benefit judicious decision making for efficient intervention implementation.

Article history

Received: 24 September 2017

Revised: 24 November 2017

Accepted: 24 November 2017

Keywords

Malaria;
Transmission window;
Fuzzy logic;
Climate suitability;
Geovisualisation.

Editor(s)

M. A. Siddiqui

1 INTRODUCTION

Geographic Information System (GIS) today supports health and disease mapping in diverse ways. Some fall in the category of medical studies – disease outbreak modelling, disease surveillance, targeting interventions and very few in the category of health geography. The study serves dual purpose, one of strengthening spatial health decision making through climate based suitability analysis and second of attempting use of fuzzy logic in visualising through maps the climate-based Malaria Transmission Suitability for Central India composing Madhya Pradesh and Chhattisgarh states. Chhattisgarh is 2nd and Madhya Pradesh is the 3rd most malarious state after Odisha in India. The present climate suitability based analysis will help in better decision making.

The study has expanded to unveil geographic dimensions of Malaria disease because as a disease it has remained a major public health challenge and endemic in most of the districts in India. During 2014, more than a million were affected by this mosquito-borne infectious disease in the country (NVBDCP). The two major human malaria species in India are *Plasmodium falciparum* (*P. falciparum*) and *Plasmodium vivax* (*P. vivax*); while *P. malariae* and *P. ovale* are rare. Studies have found that distribution and seasonality of malaria depends on the seasonal characteristics of climate (Gill, 1921; Craig et al., 1999; Grover-Kopce et al., 2006). Temperature, rainfall and humidity are the major climatic driving forces for malaria transmission (Dhiman et al., 2008; Garg et al.,

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2009; Dhiman *et al.*, 2010; Bhadra *et al.*, 2011; Bush *et al.*, 2011; Cash *et al.*, 2013). Suitable temperature supports the mosquito larval development rate, the frequency of blood feeding, and malaria parasites to mature in female mosquitoes. Rainfall boosts moisture in the air and creates breeding sites for mosquitoes. Humidity helps to prolong the life of the vector and develops conditions for transmission under suitable temperature.

The first known extensive use of the GIS technology in the field of malaria study was by MARA/ARMA (Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique) project. The mentioned project in Africa used fuzzy logic to model climate suitability for stable malaria transmission in Africa, based on temperature, rainfall, and malaria parasites and their vector development (MARA, 1998). Therefore, in the present study we have made an attempt to map climate-based malaria transmission suitability using fuzzy logic for Central India.

2 METHODOLOGY

2.1 Study Area

Madhya Pradesh is situated in the central part of India (Figure 1) with an area of 305.3 thousand km² of which forest covers about 31% of the total land area. Chhattisgarh is comparatively smaller state with an area of 135,194 km² of which 45% is under forest cover. The climate of the region is characterized by a hot summer (March-June), monsoon/rainy seasons (July-October) and a cool/autumn seasons (November-February). The area receives good annual rainfall which ranges between 1400 to 2000 mm.

Malaria in this region is transmitted by two efficient vectors i.e. *Anopheles culicifacies* and *An. fluviatilis*. In Madhya Pradesh (MP) and Chhattisgarh districts having more than 25% tribal population have been brought under Enhanced Malaria Control Project (EMCP). The gravity of the problem can be assessed

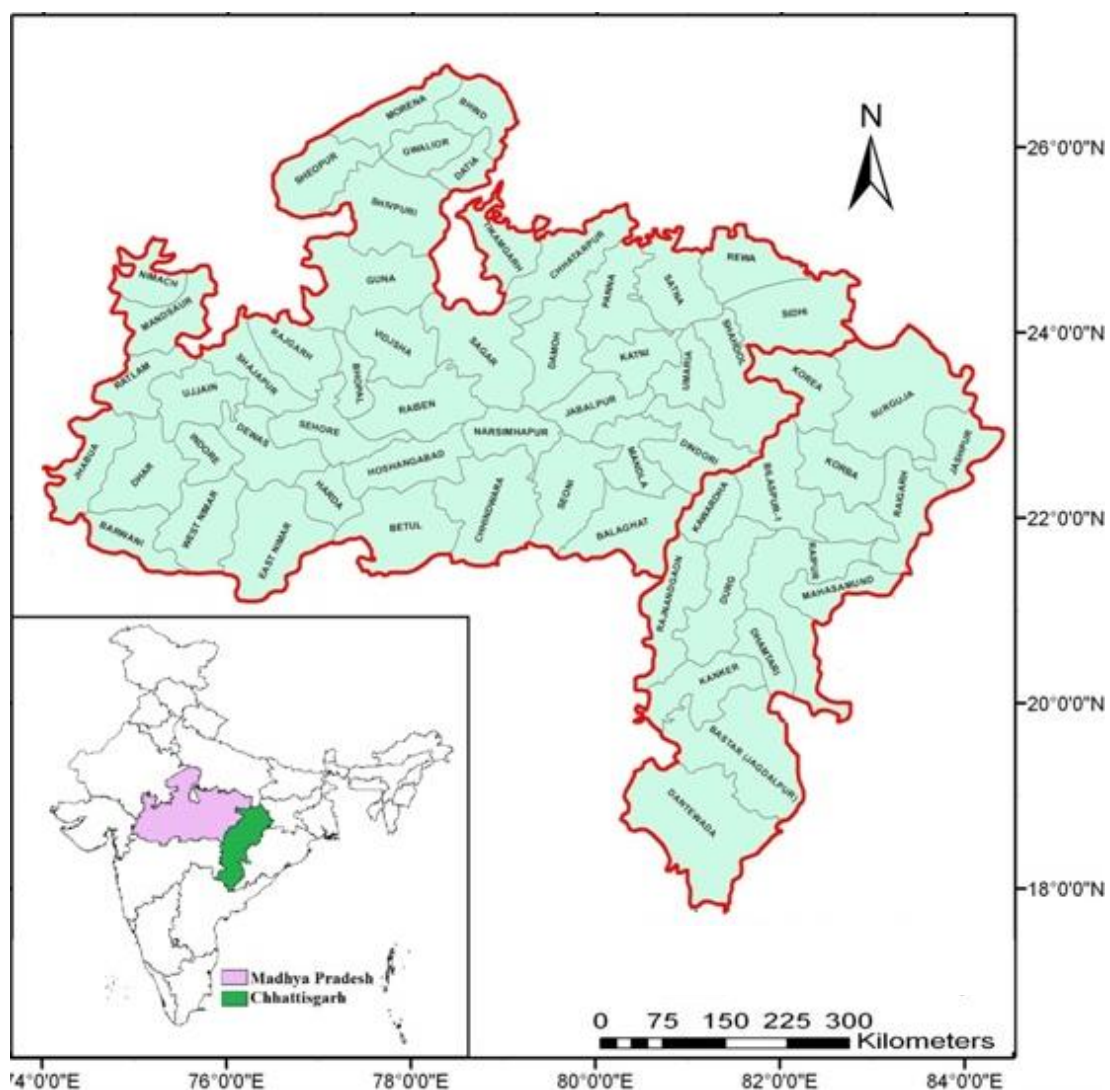


Figure 1. Study area: Madhya Pradesh and Chhattisgarh states

by the fact that in MP (population 63,668,000), 19% population of the 15 districts of state is under EMCP which contribute 53% malaria and 71.5% *P. falciparum* cases. Similarly Chhattisgarh has a total population of 23,070,000 of which 41% are under EMCP, which contribute 91% of malaria and 96% of *P. falciparum* cases in the state.

2.2 Datasets and Climatic Indicators

District wise meteorological data for 2008 was used for the present study. 2008 was characterized by nearly normal distribution of precipitation (98% of its long period average) over most parts of the country during SW monsoon, normal NW monsoon activity over south peninsula, and comparatively smaller positive temperature anomaly than the previous years (IMD). Previous studies (Gill, 1938; Russel et al., 1946) have considered the influence of temperature and humidity on mosquito to be inseparable. Therefore, temperature and relative humidity were selected as the two indicators for malaria transmission suitability analysis.

2.3 Suitability Mapping Framework

Monthly temperature and relative humidity interpolation maps were generated using 'Natural Neighbor' interpolation algorithm. This method allows the creation of highly accurate and smooth surface models from very sparsely distributed datasets (Harman and Johns, 2008). The generated interpolated maps were later classified into fuzzy subsets by fuzzy membership functions. Previous studies have shown that temperature ranging between 18°C and 32°C, and relative humidity between 55 and 80 percent are suitable for malaria transmission (Bhattacharya et al., 2006). However, vector survival is least at humidity less than 40 (Bayoh, 2001; Yamana and Eltahir, 2013). For both the indicators trapezoidal membership function was selected. Arc GIS software and its FUZZY tool were used for the whole

methodology. There are various membership functions available in the software: fuzzy Gaussian, fuzzy linear, fuzzy near, fuzzy more, fuzzy MS more, fuzzy small, and fuzzy MS small. Since present study used trapezoidal function, Raster Calculator (with conditional function) was used for fuzzification of the monthly temperature and relative humidity (RH) interpolated maps under trapezoidal membership function, whereby datasets were converted to fractions between 0 (Not suitable) and 1 (Most suitable). For temperature index, 'a' represents the lower threshold (18°C), 'd' represents the upper threshold (32°C) beyond which the membership function is 0; whereas, 'b' and 'c' represents 24°C and 28°C respectively, since this range has been identified as most suitable range for malaria transmission (Bhattacharya et al., 2006; Mordecai et al., 2013), the membership function is 1. Similarly for RH scalar parameters a, b, c and d are 40, 55, 80 and 100 respectively, where the membership function for range 55% and 80% is 1, and as the value moves away from the range towards 40 or 100, the membership function decreases to 0 representing 'not suitable'. Therefore the selected trapezoidal membership functions for temperature (equation 1) and humidity (equation 2).

Fuzzy classified monthly temperature maps and relative humidity maps were overlaid through fuzzy intersection based AND operator to generate monthly climate suitability maps. Monthly suitability maps were further aggregated using raster calculator to generate the final 'Climate Suitability Map' representing length of transmission windows for 2008 (Figure 2). Further, to analyze relevance of the climate suitability with the malaria cases distributions, 2008 climate suitability map was overlain by the region's Annual Parasite Incidence (API).

Temperature:

$$f(x; 18, 24, 28, 32) = \begin{cases} 0, & x \leq 18 \\ \frac{x-18}{24-18}, & 18 \leq x \leq 24 \\ 1, & 24 \leq x \leq 28 \\ \frac{32-x}{32-28}, & 28 \leq x \leq 32 \\ 0, & x \geq 32 \end{cases} \quad (1)$$

Relative Humidity:

$$f(x; 40, 55, 80, 100) = \begin{cases} 0, & x \leq 40 \\ \frac{x-40}{55-40}, & 40 \leq x \leq 55 \\ 1, & 55 \leq x \leq 80 \\ \frac{100-x}{100-80}, & 80 \leq x \leq 100 \\ 0, & x \geq 100 \end{cases} \quad (2)$$

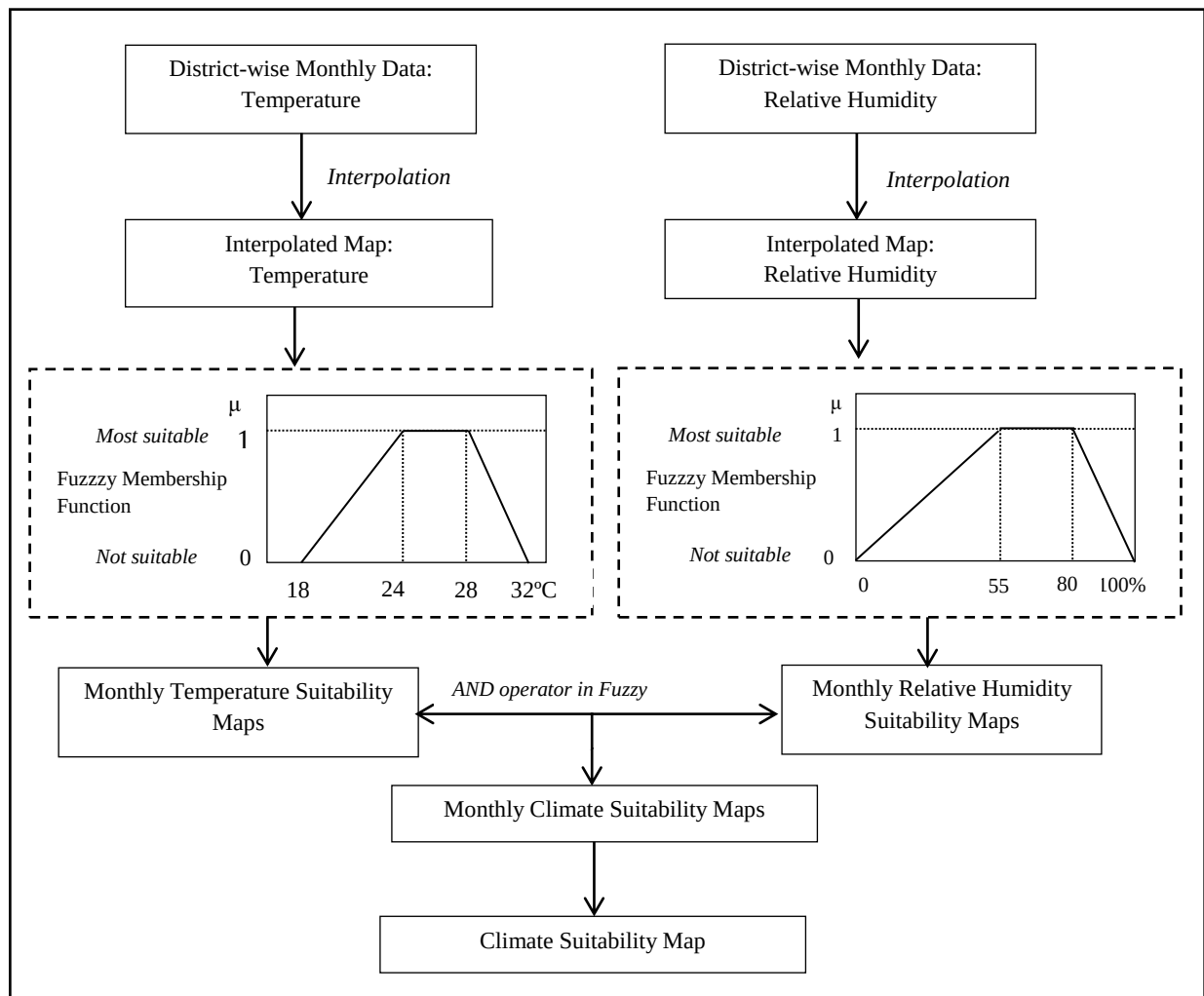


Figure 2. Conceptual framework of climate suitability mapping for malaria transmission

3 RESULT AND DISCUSSION

Fuzzy sets express how the transition of variables from one to another takes place, thus, it offers a better approach to climate suitability classification for malaria transmission than discrete sets. Figure 3 shows the fuzzy based temperature suitability for stable malaria transmission in Central India for 2008. Areas where temperature is most suitable in a month are denoted with dark shade (fuzzy value of > 0.9). Lighter/brighter tone indicates locations where suitability is least for malaria transmission (fuzzy value of < 0.1). Temperature suitability for malaria transmission across the region varies between months. Most parts of the Central India remains unsuitable during April and May due to high temperature.

Figure 4 shows the fuzzy based humidity suitability for stable malaria transmission in Central India for 2008. Areas with most suitable humidity in a month are denoted with dark gray shades (fuzzy value of > 0.9), which gradually descends to lighter tone indicating areas where suitability is least for malaria

transmission (fuzzy value of < 0.1). The study area remains least suitable during winter and summer months due to low humidity ($RH < 50\%$). Compared to Chhattisgarh, Madhya Pradesh experiences more numbers of least suitable months i.e. February, March, April and May.

The Monthly Climate Suitability Maps (Figure 5) generated from fuzzy intersection of temperature and relative humidity maps show that there is great variation in climate suitability within a month across the region. Areas with most suitable climate for transmission in a month are denoted with dark blue shades (fuzzy value of > 0.9), which gradually descends to lighter tone indicating areas where suitability is least for malaria transmission (fuzzy value of < 0.1). During winter (January, February and March) Northern half of India region remains unsuitable for malaria transmission. During April and May, more than 80% of the study region remain unsuitable for malaria transmission. Climate suitability improves with the onset of monsoon in most parts of the region.

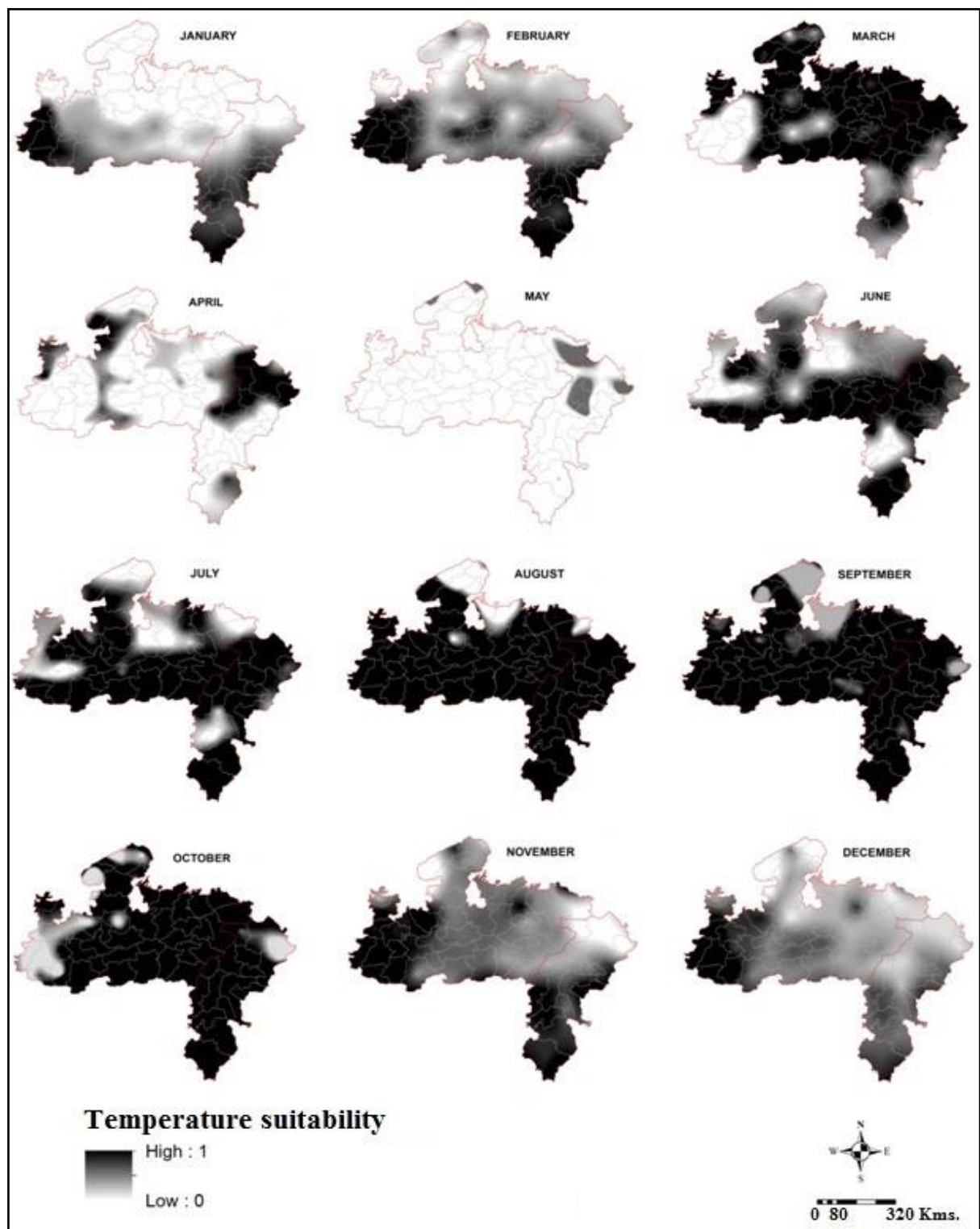


Figure 3. Monthly temperature suitability maps for malaria transmission in Central India

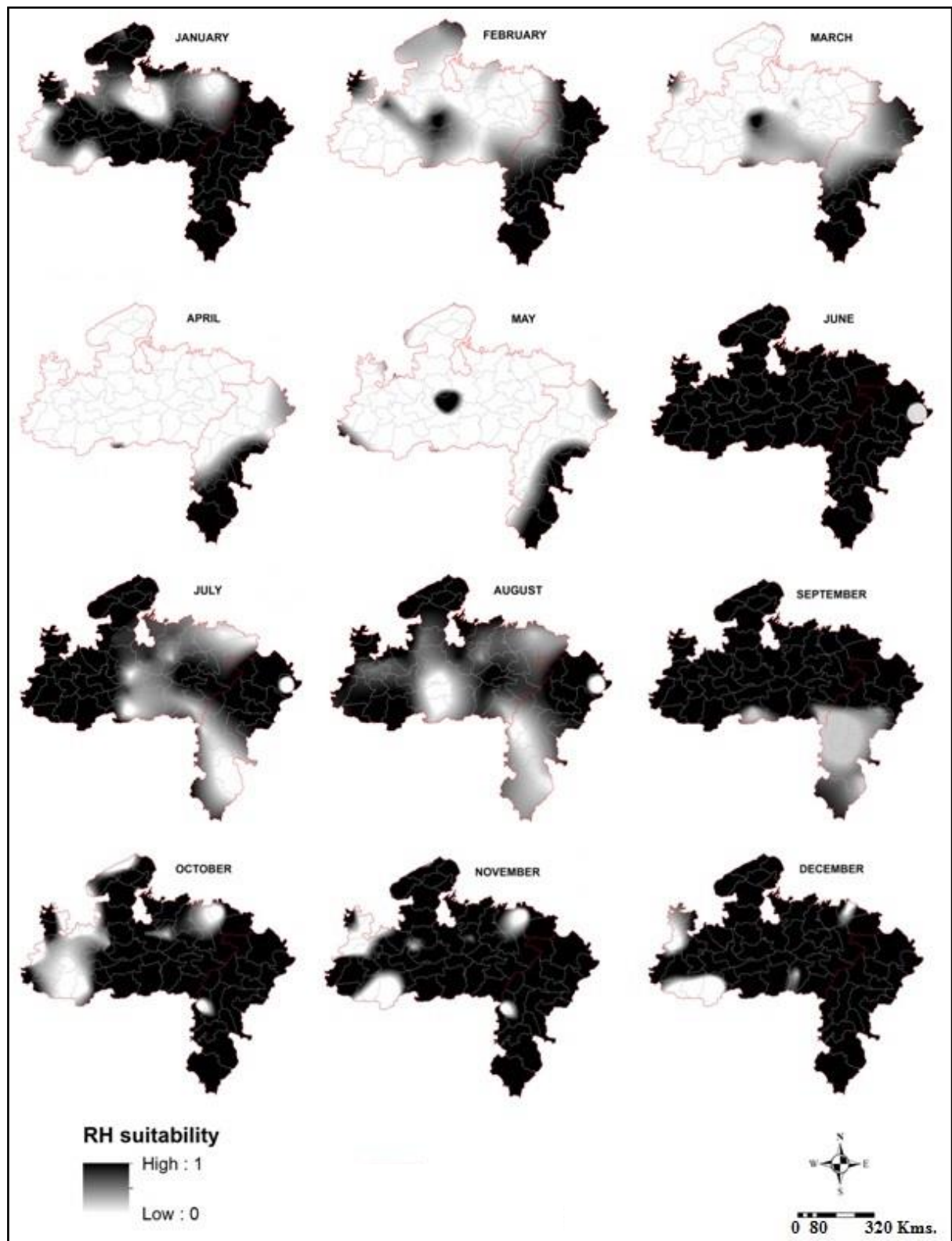


Figure 4. Monthly relative humidity suitability maps for malaria transmission in Central India

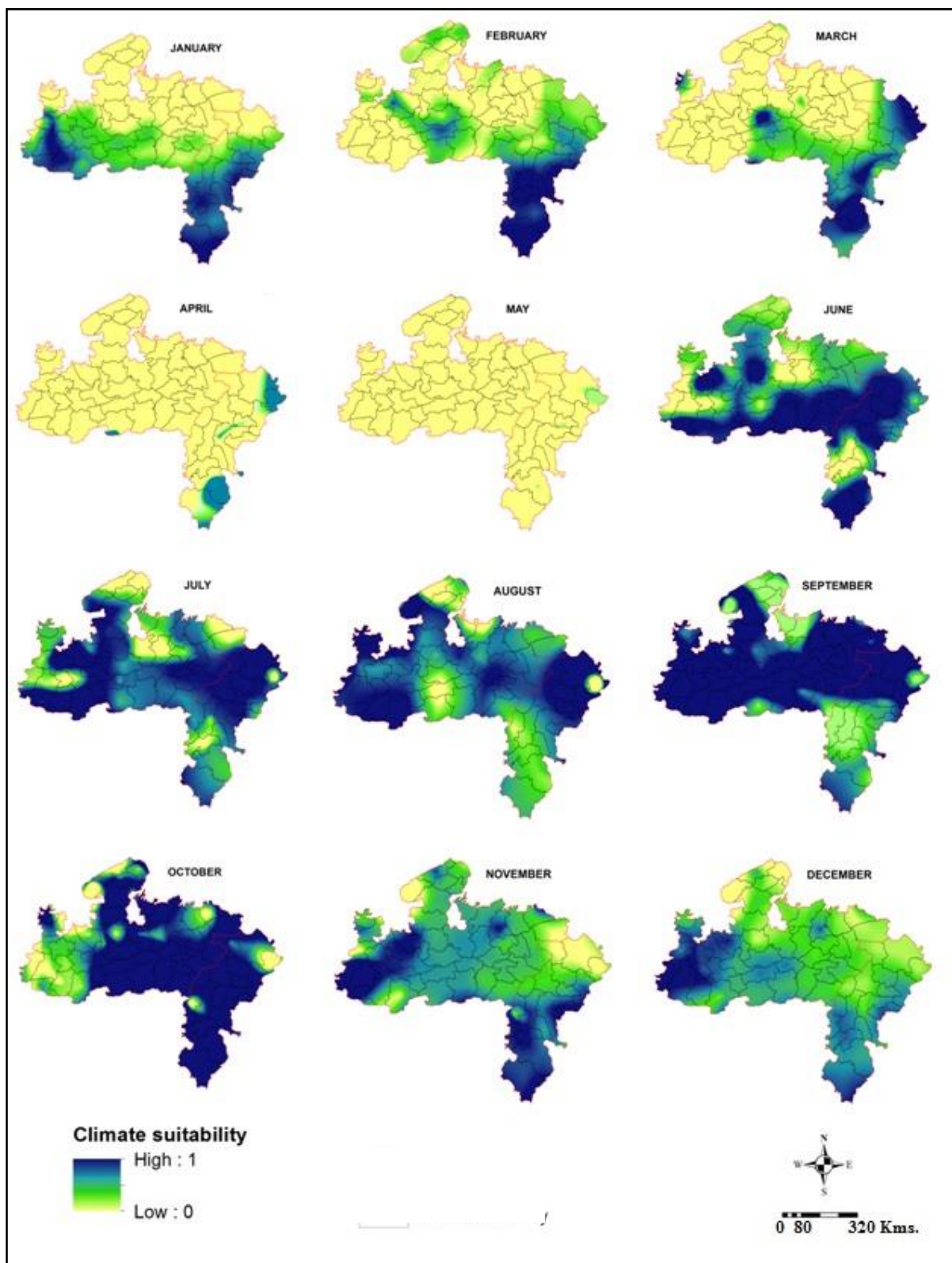


Figure 5. Monthly climate suitability maps for malaria transmission in Central India

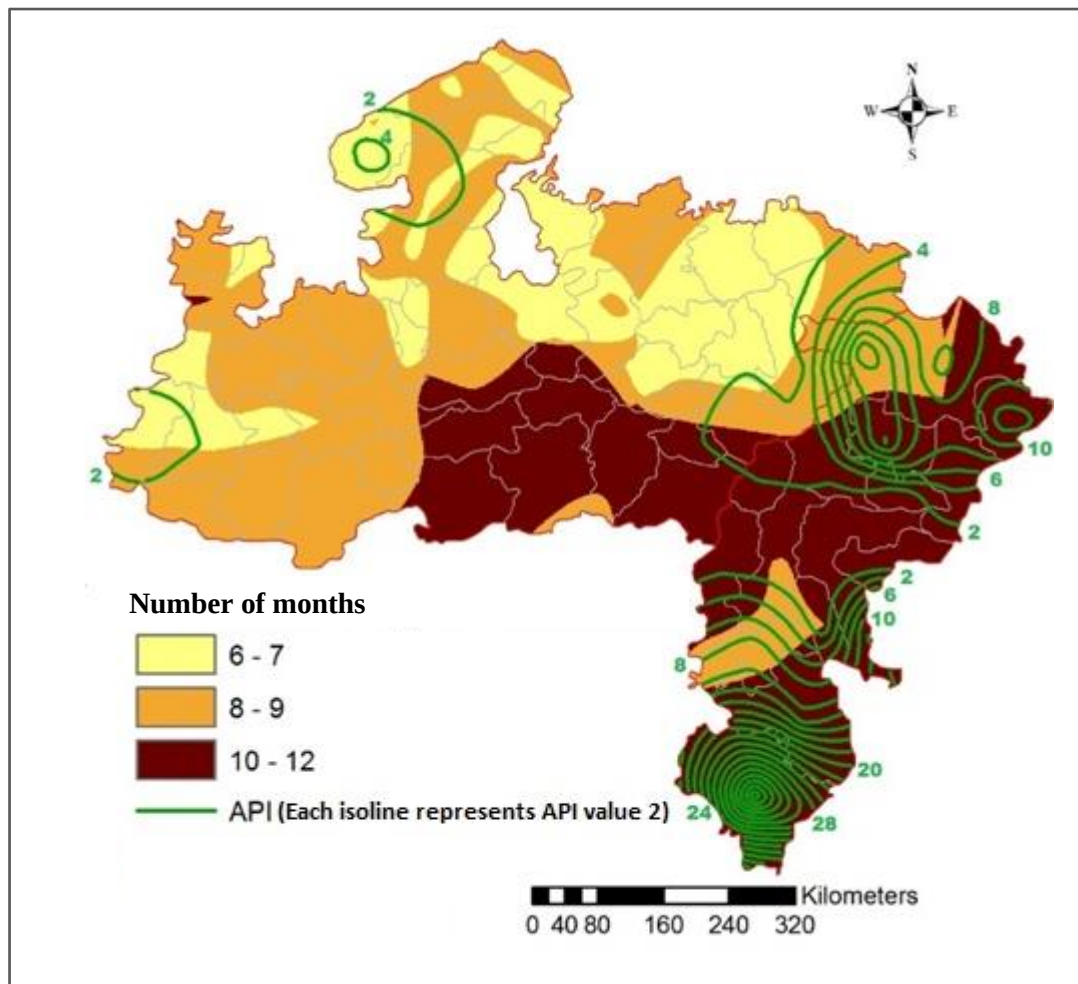


Figure 6. Climate suitability map for malaria transmission and API overlay

Climate Suitability Maps for malaria transmission (Figure 6) shows the spatial distribution of Transmission Window length (in months) across the region during 2008. During 2008, most districts of Chhattisgarh and very few districts of Madhya Pradesh have transmission window open for more than 10 months and are identified as 'High Endemic Regions'. Regions with 8-9 months of transmission windows are mostly in Madhya Pradesh, and remaining districts of Chhattisgarh, are identified as 'Endemic Regions'. Rest of Madhya Pradesh has transmission window open for 6-7 months, and are 'Epidemic Prone Regions'.

A high positive correlation for number of climatically suitable malaria transmission months and API can be observed in the study region. That is the regions, where climate suitability remains for 10 months and above, have more than 2 API. However, except few patches in Madhya Pradesh, rest of the regions have API less than 2. These low API regions however may experience outbreaks due to some other factors. Therefore, it can be concluded that fuzzy logic based methodology has appropriately mapped the climate suitability based malaria transmission in Central India.

4 SUMMARY

The fuzzy logic based climate suitability mapping methodology has efficiently identified the seasonal cycle of malaria transmission, and finally, mapped the climate suitable endemic and epidemic-prone areas in Central India. Inter-variation of climate suitability within the region can be well analyzed with the application of fuzzy logic. Therefore, the accuracy of the generated climate suitability map is high, which will help in forewarning and judicious decision making for efficient intervention implementation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

Acknowledgments are due to Survey of India, Census of India, Directorate of Health Services, Madhya Pradesh and ESRI Arc GIS software.

ABBREVIATIONS

API: Annual Parasite Incidence; **EMCP:** Enhanced Malaria Control Project; **GIS:** Geographic Information

System; **IMD**: Indian Meteorological Department; **NVBDCP**: National Vector Borne Disease Control Programme; **RH**: Relative Humidity.

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